Hydrologic Benchmark Network Stations in the Western U.S. 1963-95 (USGS Circular 1173-D)

Crater Lake near Crater Lake, Oregon (Station 11492200)

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This report details one of the approximately 50 stations in the Hydrologic Benchmark Network (HBN) described in the four-volume U.S. Geological Survey Circular 1173. The suggested citation for the information on this page is:

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All of the tables and figures are numbered as they appear in each circular. Use the navigation bar above to view the abstract, introduction and methods for the entire circular, as well as a map and list of all of the HBN sites. Use the table of contents below to view the information on this particular station.

Site Characteristics and Land Use

Crater Lake is located in the Sierra-Cascade Mountains physiographic province along the crest of the Cascade Range in southwestern Oregon ([Figure 18](#). *Map showing the Crater Lake Basin and photograph showing Wizard Island and crater rim*). Crater Lake occupies the collapsed caldera of Mount Mazama and has an average surface elevation of 1,882 m, a surface area of 53.2 km2, and a maximum depth of 589 m (Larson and others, 1993). The 67.8-km2 drainage basin consists of the lake (53.2 km2) and the steep walls of the caldera (14.6 km2), which reach a maximum elevation of 2,484 m (Larson and others, 1996). The HBN station is located along the northeast shore of the lake in Cleetwood Cove at latitude 42°58'45" and longitude 122°04'45". The lake receives 85 percent of its inflow by direct precipitation, and the remainder comes from about 40 springs and streams that emanate from the caldera walls (Redmond, 1990). There is no surface flow out of the lake, and the lake level is maintained by a balance between evaporation (28 percent) and seepage from the lake bottom (72 percent) (Redmond, 1990). The lake elevation varies annually by about 60 cm in response to seasonal variations in precipitation and vaporation. The minimum and maximum lake elevations on record were 1,878.5 m on September 10, 1942, and 1,883.5 m on March 25, 1975 (Hubbard and others, 1996). The climate of Crater Lake is discussed in detail by Redmond (1990). Average monthly air temperatures range from -3.5°C in January to 12.8°C in August (URL http://www.wrcc.sage.dri.edu, accessed 1998). Precipitation averages 172 cm annually and is strongly seasonal; December (28.9 cm) and January (10.6 cm) are the wettest months and July (2.1 cm) and August (2.4 cm) are the driest. Winter snowfall averages 1,350 cm/yr and accumulates in a seasonal snowpack between November and March that usually reaches 300 cm in depth. Despite the large amount of snow, the lake almost always remains free of ice and snow during winter.

The basin is in the subalpine zone of the Sierran Steppe ecoregion (Bailey and others, 1994). Vegetation on the crater rim is dominated by mature conifer forests of mountain hemlock, red fir, and whitebark pine (Gregory and others, 1990). Small shrubs, herbaceous plants, and Sitka alder grow in thickets along springs and seeps that emanate from the crater walls. A description of the ecology of the lake itself is beyond the scope of this report but can be found in Drake and others (1990) and Larson and others (1993).

The geologic setting and history of Crater Lake are summarized by Bacon and Lanphere (1990). Crater Lake partly fills an 8- by 10-km-diameter caldera that collapsed during the eruption of Mount Mazama about 6,850 years ago (Bacon and Lanphere, 1990). The walls of the caldera consist of andesitic and dacitic lavas that primarily consist of plagioclase (An50), pyroxene, and sodium-rich volcanic glass (Nathenson and Thompson, 1990). The floor of the caldera is filled by intercaldera tuffs and interbedded landslide deposits that are covered by a thin layer of lake sediment. The lake sediment represents a mixture of material from three sources-volcanic debris from the caldera walls, biogenic particulates that settle out from the lake water, and iron oxide precipitates that form where hydrothermal fluids vent from the lake floor (Dymond and Collier, 1990). Soil development on the crater walls is hindered by steep slopes and frequent
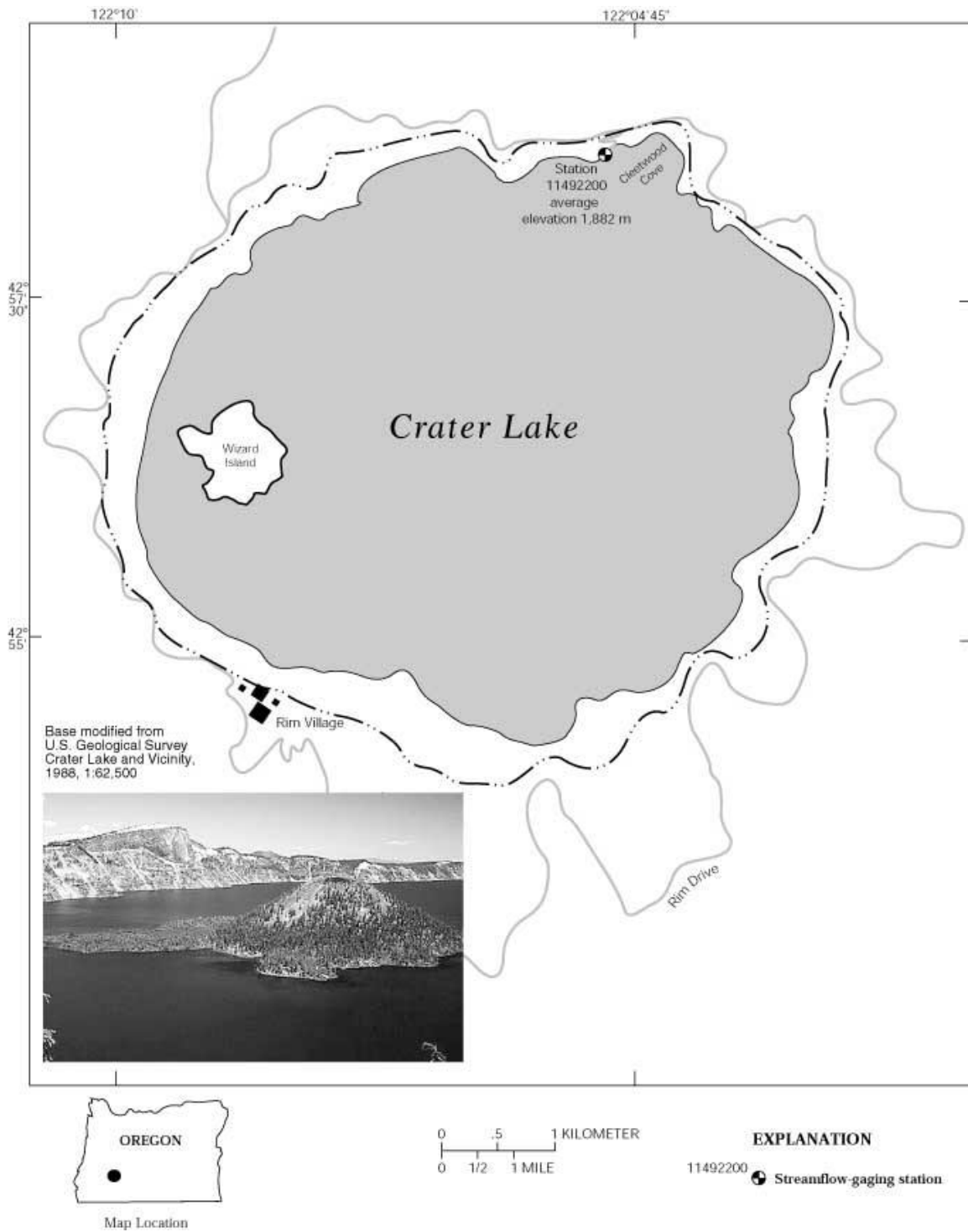
Figure 18. *Map showing the Crater Lake Basin and photograph showing Wizard Island and crater rim*

avalanches, and most of the slopes are covered by loose accumulations of gravel, cobbles, and boulders (Gregory and others, 1990).

The Crater Lake HBN Basin is located in Klamath County in Oregon and is entirely in the boundaries of Crater Lake National Park. The park was established in 1902, and more than 90 percent of the park is managed as wilderness (U.S. Department of the Interior, 1995). A 53-km paved road, referred to as Rim Drive, follows the crater rim around the perimeter of the lake. The road is closed each year in mid-October because of winter snows and is plowed each spring, beginning in mid- April, to reach the north entrance of the park by mid-June. During the snow-free months, the only access to the shore of the lake is from a steep 1.8-km hiking trail between Rim Drive and the boat ramp at Cleetwood Cove. More than 500,000 people visit the park annually; the heaviest use is in July and August. The only park facilities in the basin boundary are a visitor center, a lodge and cafeteria, a sewage-disposal facility at Rim Village on the south side of the lake, several picnic areas along Rim Drive, and a research station on Wizard Island. The sewage-disposal facility at Rim Village consists of a septic tank that discharges as much as 62,000 m3 of domestic wastewater each year into a drainfield that is situated 200 m above the surface of the lake (Larson and others, 1990). Recent studies of the chemistry of springs emanating from the crater walls indicate that the drainfield has increased nitrate concentrations in springs below the Rim Village that discharge directly into the lake (Larson and others, 1990).

In response to indications that the clarity of the lake might be declining, the U.S. Congress mandated a 10-year limnological study of Crater Lake (Public Law 97-250) in the fall of 1982 (Larson, 1990). The goals of the study were to develop a reliable data base for the lake, improve understanding of lake components and processes, establish a long-term program to monitor changes in the lake, and determine if the lake had changed in response to environmental stressors (Larson and others, 1993). The study concluded that long-term changes in lake clarity could not be verified because of the lack of historical data but identified climate change, air pollution, onsite automobile and boat use, and nonnative fish as the greatest human-related threats to the ecosystem. The results of scientific investigations conducted as part of this limnological program are compiled in a technical report published by the National Park Service in 1993 (Larson and others, 1993).

Historical Water-Quality Data and Time-Series Trends

The data set for the Crater Lake HBN station analyzed for this report includes 91 water-quality samples that were collected from June 1967 through September 1995. Sampling frequency averaged only three samples per year because of closure of the access road in winter. Samples from the early part of the period of record probably were analyzed at a USGS district laboratory in Portland, Oreg. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and the NWQL in Arvada, Colo., from 1976 to 1995. Lake stage for Crater Lake (station 11492200) is available beginning in October 1961, and daily water temperature at the station has been measured since October 1963.

Calculated ion balances for 86 samples that have complete major-ion analyses are shown in figures 19a and 19b. *Graphs showing temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Crater Lake, Oregon.* Ion balances ranged from -10 to +9.6 percent, and 85 percent of the samples had values within the ±5-percent range, indicating that the analytical results are of high quality. The average ion balance for all samples was -1.0 percent, and 65 percent of samples had a slight excess of measured cations compared to measured anions, indicating that unmeasured constituents, such as organic anions, may have contributed a small amount to the ionic content of lake water at this HBN station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects (fig. 19). The most notable pattern is in field pH, which increased rather abruptly in 1988. Several uncharacteristically high calcium and sodium concentrations were measured during the 1970's. In addition, the scatter in calcium, alkalinity, and chloride concentrations decreased noticeably during the period of record. Because the surface-water chemistry at this station should be relatively stable due to the long residence time of water in the lake, these patterns probably are caused by sampling or analytical artifacts rather than by natural variability in lake chemistry.

Table 34. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Crater Lake, Oregon, June 1967 through September 1995, and volume-weighted mean concentrations in bulk precipitation collected at Crater Lake National Park, Oregon

[Concentrations in units of microequivalents per liter, lake stage in feet, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of lake samples; VMW, volume-weighted mean; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Lake Water						Precipitation VMA[a]
	Minimum	First Quartile	Median	Third Quartile	Maximum	n	
Lake Stage	1,879.47	1,881.44	1,881.77	1,882.56	1,883.32	88	--
Spec. cond., field	110	110	120	120	130	81	--
pH, field	6.8	7.2	7.5	7.7	8.0	77	5.3
Calcium	320	340	350	360	500	91	4.6
Magnesium	160	210	210	220	260	91	2.0
Sodium	410	440	480	480	830	90	3.1
Potassium	36	44	46	49	59	90	1.7
Ammonium	<.7	<.7	1.4	2.9	11	44	1.8
Alkalinity, laboratory	400	580	600	600	800	88	--
Sulfate	120	210	210	230	420	90	7.5
Chloride	190	270	280	310	450	91	11
Nitrite plus nitrate	<.7	3.6	7.1	7.1	11	65	2.6
Silica	230	280	300	300	330	90	--

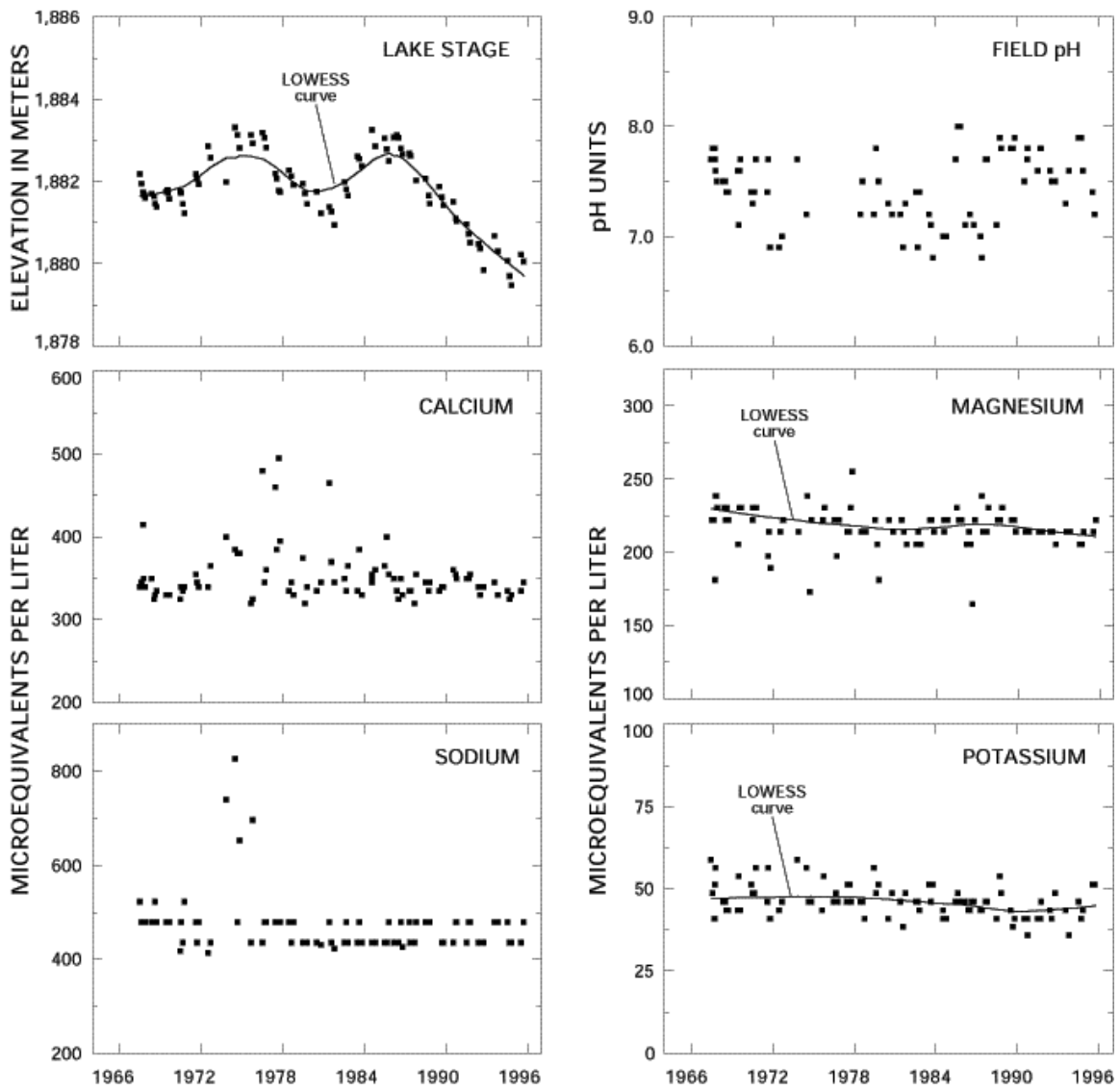[a] Values are volume-weighted mean concentrations for 1987-88 (Nelson and others, 1993).

Figure 19a. *Graphs showing temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Crater Lake, Oregon*
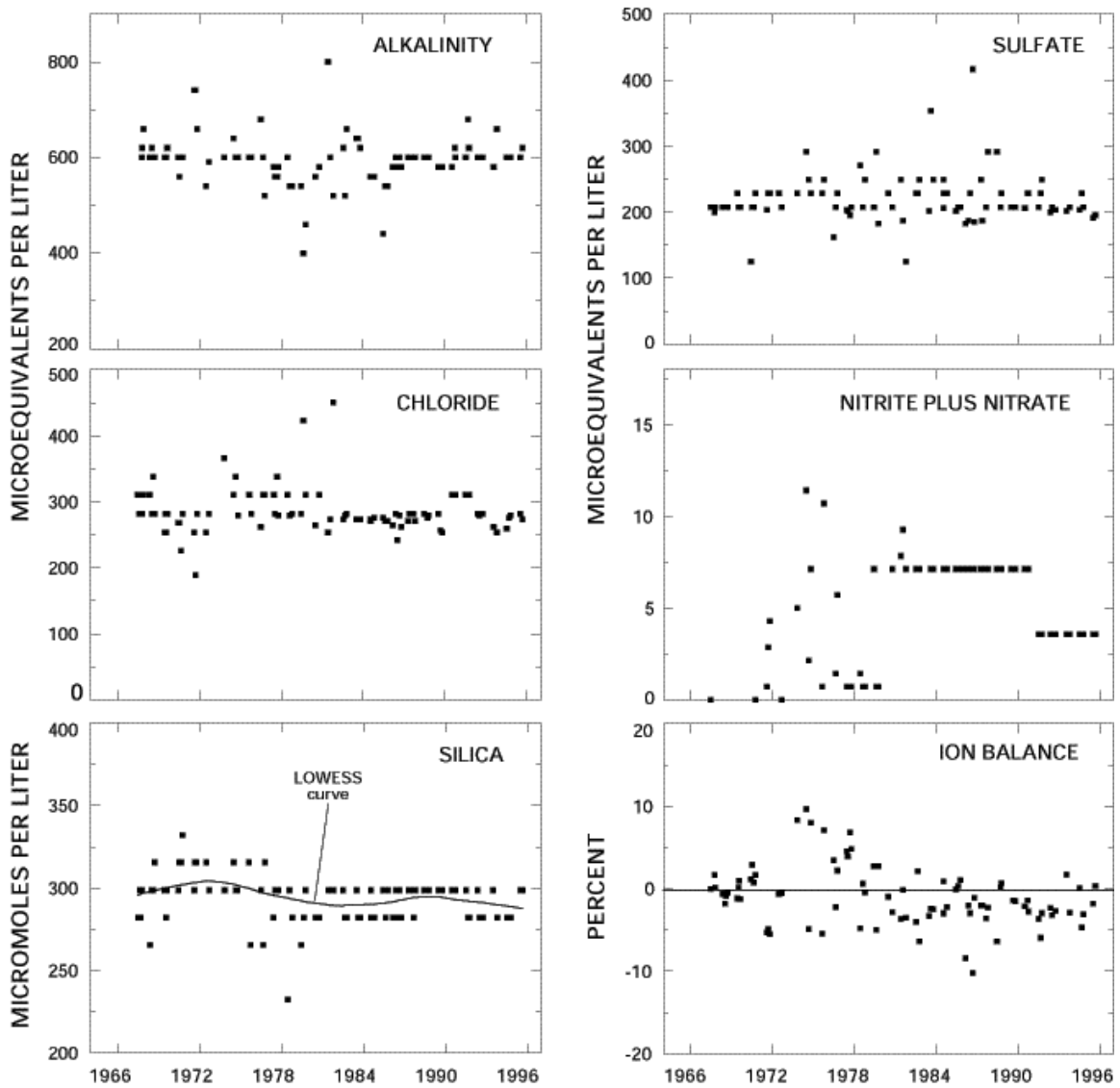
Figure 19b. *Graphs showing temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Crater Lake, Oregon - Continued*

The median concentrations and ranges of major dissolved constituents in lake water collected at the HBN station and VWM concentrations in bulk precipitation collected in Crater Lake National Park are presented in table 34, and correlations between lake stage and the major solutes are presented in table 35. Precipitation chemistry in the park is very dilute and slightly acidic and has a VWM pH of 5.3. The predominant cations in precipitation were hydrogen ion, calcium, and sodium, which contributed 27, 25, and 17 percent of the total cation charge, respectively. The predominant anions were sulfate and chloride, which accounted for 36 and 51 percent of the total anions, respectively. Lake-water samples from Crater Lake are moderately concentrated and well buffered; specific conductance ranged from 110 to 130 mS/cm, and alkalinity ranged from 400 to 800 meq/L (table 34). The predominant solutes in lake water were sodium, calcium, bicarbonate, silica, and concentrations of most solutes in lake water were much higher than concentrations in precipitation despite the fact that the lake receives 85 percent of its inflow from direct precipitation (Nelson and others, 1993). Sources of solutes other than atmospheric deposition include dissolution of geologic materials on the lakebed, springs and small streams that emanate from the caldera walls, and hydrothermal sources under the lake. The predominance of sodium compared to calcium and the high concentrations of dissolved silica in lake water are consistent with the weathering stoichiometry of sodium-rich volcanic glass and plagioclase minerals in the volcanic bedrock (Nathenson and Thompson, 1990). The elevated chloride and sulfate concentrations in lake water cannot be accounted for by either atmospheric deposition or bedrock weathering and may be derived from thermal springs that discharge from the floor of the lake (Van Denburgh, 1968). Biological activity also functions as a control on the solute budget of the lake. For example, diatom activity in the lake removes as much as 30 percent of the dissolved silica introduced from weathering and thermal sources (Nelson and others, 1996). More than 90 percent of the nitrate and ammonium that enters the system in atmospheric deposition is assimilated by algae and subsequently buried in sediments on the bottom of the lake (Dymond and others, 1990). All solute concentrations were poorly correlated with lake stage and with each other because of the extremely constant chemical composition of the lake (table 35). More detailed information on the processes controlling the chemistry of Crater Lake is presented in Nathenson and Thompson (1990), Larson and others (1996), and Nelson and others (1996).

Table 35. Spearman rank correlation coefficients (rho values) showing the relation among lake stage, pH, and major dissolved constituents, Crater Lake, Oregon, 1967 through 1995

[Ca, calcium, Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO4, sulfate; Cl, chloride; N, nitrite plus nitrate; Si, silica]

	Stage	pH	Ca	Mg	Na	K	Alk	SO$_4$	Cl
pH	-0.377	--	--	--	--	--	--	--	--
Ca	-.176	-0.017	--	--	--	--	--	--	--
Mg	.207	.011	0.017	--	--	--	--	--	--
Na	-.069	.253	.160	0.304	--	--	--	--	--
K	.189	.038	.082	.266	0.179	--	--	--	--
Alk	-.230	.061	-.049	.030	.312	0.024	--	--	--
SO$_4$	.225	-.019	-.001	-.015	.333	-.142	0.169	--	--
Cl	-.223	.149	.143	-.068	.266	.141	-.034	0.062	--
Si	-.006	-.007	.110	.262	.097	.093	.107	-.105	-0.056

Table 36. Results of the seasonal Kendall test for trends in lake stage and unadjusted pH and major dissolved constituents, Crater Lake, Oregon, June 1967 through September 1995

[Trends in units of microequivalents per liter per year, except for stage in meters per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted	
	Trend	p-value
Lake stage	-0.04	0.000
pH, field	.01	.035
Calcium	<.1	.301
Magnesium	<.1	.008
Sodium	<.1	.041
Potassium	-.3	.001
Alkalinity, laboratory	<.1	.778
Sulfate	<.1	.423
Chloride	-.2	.044
Nitrite plus nitrate	<.1[a]	.039
Silica	<.1	.007

[a] Trend calculated for 1971-95 using a test for censored data.

The results of the seasonal Kendall test for trends in lake stage and unadjusted dissolved constituents are listed in table 36. Trends were not calculated for the stage-adjusted concentrations because correlations between solute concentrations and lake stage were not significant at the 0.10 probability level. Statistically significant trends were detected in lake stage and unadjusted magnesium, potassium, and silica concentrations at the 0.01 probability level. The LOWESS curve for lake stage in figure 19 shows that the trend in lake stage was primarily caused by declining lake levels at the end of the period of record. Given that climate variability can account for lake-level changes during the last century (Redmond, 1990), this decline was probably caused by a period of dry and warm weather in the south-central part of Oregon that persisted from about 1985 to 1995 (Oregon Climate Service, at URL http://www.ocs.orst.edu, accessed 1998). Trends in water- quality constituents at this HBN station were not expected because the water column is well mixed and the residence time of water in the lake is around 225 years (Collier and others, 1990). In addition, the trends are inconsistent with the results of Larson and others (1996) who reported no long-term changes in lake chemistry during a 10-year limnological study of the lake nor with a comparison of recent and historical data. Closer inspection of the trend results in table 36 reveals that the change in magnesium and silica concentrations was less than 0.1 percent during the entire period of record. Because the analytical precision of these analyses is no better than 5 percent (Fishman and Friedman, 1989), the statistical test probably did not detect measurable changes in the concentrations of these two constituents. The trend in potassium was considerably larger in magnitude than the trends in magnesium and silica and amounted to a total decrease in concentration of about 17 percent, most of which occurred in the latter part of the period of record (fig. 19). The cause of the downward trend in potassium could not be identified. One possibility is a method-related artifact, although there were no documented changes in the analytical technique for potassium since 1965 (Fishman and others, 1994). Alternatively, potassium concentrations may have been affected by the decline in lake level that occurred from 1985 to 1995.

Synoptic Water-Quality Data

Synoptic samples were not collected in the Crater Lake HBN Basin as part of this study because the lake receives only 15 percent of its annual water input from surface runoff. Several studies, however, have investigated the chemistry of springs and streams emanating from the caldera walls and along the flanks of Mount Mazama (Thompson and others, 1987; Greogory and others, 1990; Nathenson and Thompson, 1990). These studies have used spring chemistry to investigate hydrologic losses from the lake and to evaluate the predominant solute sources to the lake.

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Appendix A. List of Map References

a. U.S. Geological Survey Topographic Maps:

- Crater Lake East, Oregon (1:24,000), 1985, HBN gaging station on this quadrangle
- Crater Lake West, Oregon (1:24,000), 1985
- Crater Lake National Park and vicinity (1:62,500), 1988

b. Geologic Maps:

- Diller, J.S., 1902, The geology and petrography of Crater Lake National Park: U.S. Geological Survey Professional Paper 3, 167 p.
- Bacon, C.R., and Lanphere, M.A., 1990, The geologic setting of Crater Lake, Oregon, in Drake, E.T., Larson, G.L., Dymond, Jack, and Collier Robert, eds., Crater Lake-An ecosystem study: San Francisco, American Association for the Advancement of Science, p. 19-27.

c. Soil surveys: No soil surveys available.

d. Miscellaneous Maps:

- U.S. Department of the Interior, 1982, Crater Lake National Park, Oregon: Washington, D.C., U.S. Department of the Interior National Park Service, scale 1:85,000.